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TRIGENERATION – POSSIBILITIES OF IMPLEMENTATION AT CERN

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Abstract

Optimum distribution of energy supply systems can result in large savings in industrial facilities and production devices. Identifying the configuration of existing equipment and its loading, in order to minimize total energy consumption and at the same time satisfy given load demands, has very high payback potential. This paper presents the principle of trigeneration, the technology that can offer a highly efficient way of converting primary fuel (gas, oil) into useful energy as electricity, heat and chilled water simultaneously. It explains different factors that must be considered for such systems to be economically feasible. Some examples of industrial trigeneration systems are analysed and discussed to illustrate the application. Also the possibility of implementation of trigeneration at CERN is discussed, taking into account the existing cogeneration system, power supply structure, secondary energy demands, as well as future developments in our energy policy.

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1 INTRODUCTION

What is trigeneration? What are the possibilities of implementing this technology at CERN? These questions will be answered in the following paragraphs. Let us start from the historical background. Trigeneration was first applied for district cooling in the USA in the early 1980s [1]. Its advantage when compared to cogeneration schemes (let alone individual generation of chilled water and heating) is the very high added value, up to four times more ‘cost efficient’ than present cogeneration plants, for the fuel and electricity prices available in the USA. Its high overall efficiency as well as numerous advantages including chilled-water storage resulted in the very fast development and aggressive promotion of trigeneration as a means of energy generation.

2 TRIGENERATION TECHNOLOGY

The word ‘trigeneration’ is used to describe the combined production of electricity, useful heat and useful cold (refrigeration), from a single primary energy source. Trigeneration is based on the principle of cogeneration technology to which a parallel production of refrigeration is added. The technique is not new: It is commonly used in district heating and cooling schemes. However, trigeneration is being used more in the oil and gas, and petrochemical industries as three products – heat, power and refrigeration – are frequently needed in many modern processes. The trigeneration principle is shown in Fig. 1.

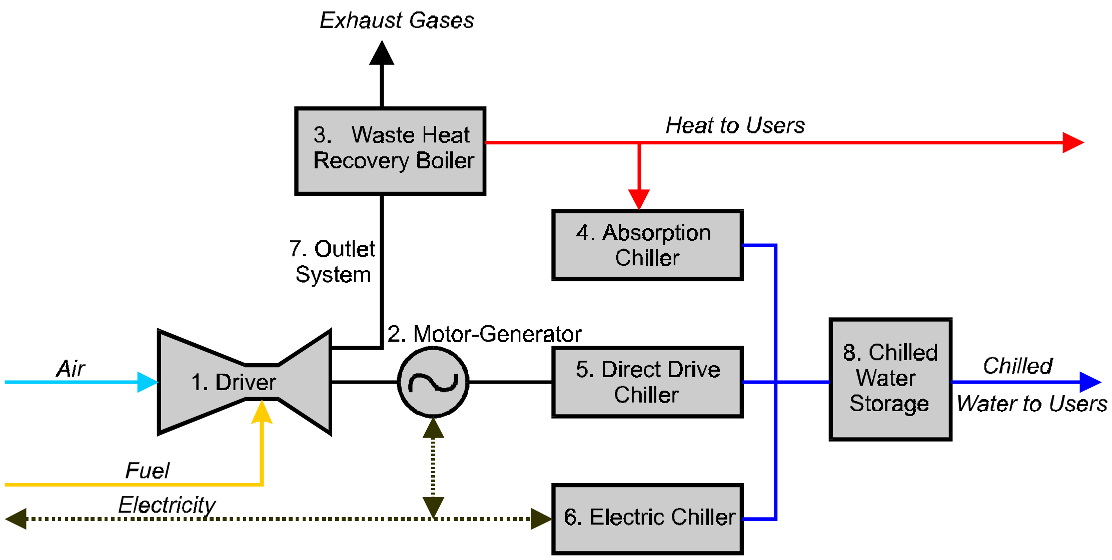

Figure 1: Schematic of a typical trigeneration unit.

The main part of the system consists of the driver (1) that can be a gas turbine, a diesel engine or a gas engine. It can operate on a wide range of gaseous and liquid fuels, which are combusted, resulting in shaft work which generates electricity in the motor-generator set (2). The exhaust gases are then directed towards the outlet system (7) that incorporates a waste-heat-recovery boiler[1] [WHRB (3)]. It is here that part of the ‘waste’ energy is recovered, being

[1] Sometimes it is called a heat-recovery steam generator (HRSG)

converted to useful heat: hot water or low-pressure steam. Since the exhaust gases leaving the driver can still contain some 14% to 15% by vol. of oxygen [2], the WHRB can be equipped with a burner placed in the exhaust duct. This arrangement is known as supplementary firing and can double the boiler steam flow although it decreases overall system efficiency. Once the exhaust gases have passed through the WHRB, they are extracted via an exhaust ducting (chimney stack) to the atmosphere. This duct can include, wherever necessary, silencer and wet NO_x controls (i.e. water or steam injection) to satisfy environmental regulations.

A part of the useful heat recovered in the WHRB is then sent to the customers for heating purposes, whereas some of this heat is used in the absorption chiller (4) to produce chilled water.

For coupling a chiller with a conventional cogeneration system, three methods can be used.

- In the first method, an absorption chiller (4) operates by consuming a fraction of the heat recovered in the WHRB. This scheme is the most commonly used in trigeneration systems due to its high energetic profits at low costs (the waste heat would otherwise be rejected to the atmosphere unless used by the chiller).
- In the second method, a compression chiller (5) is driven by a direct coupling to the driver's shaft using the excess of mechanical power. In these schemes the energetic balance must be well established in order to assure the right production of electricity and refrigeration throughout the operation period.
- The third way of producing the chilled water in the trigeneration systems is means of by a conventional compression chiller (6) using electricity as driving energy. These chillers can be powered independently of the power generation assured by a driver. Nowadays, they work on refrigerants that have no ODP (Ozone Depletion Potential), or GWP (Greenhouse Warming Potential), like ammonia, hydrofluorocarbons (HFCs) and water.

The required refrigeration plant rating (and thus investment and operation costs) can often be reduced by installing chilled water storage (8). The storage is filled during off-peak periods and later used to provide refrigeration during peak periods [3].

2.1 Main equipment

Different trigeneration configurations may be used for producing electric power, heat and refrigeration, using various equipment combinations of which the main components are described below.

2.1.1 Drivers

Gas turbines are the most often used in the trigeneration schemes. They are available as single-shaft or two-shaft models [4]. In the former, the combustion air compressor and power turbine are mounted on the same shaft whereas in the second they are mounted on the mechanically separate shafts in order to ensure better regulation and efficiency over the whole operation period. The turbines have electric efficiencies of around 25% to 35% for the industrial designs where the weight and space considerations are less important and some 30% to 40% for the compact aircraft engines.

Gaseous fuels used in the turbines can vary from natural gas to a number of not so common process gases, including refinery off-gases. Liquid fuels range from light distillates to gas oil. To reduce otherwise excessive maintenance when using these heavy fuels, and to obtain a reasonable service life, special fuel handling and treatment facilities must be provided.

Gas and diesel engines can be divided into two groups: low-speed industrial engines that run a minimum of 30,000 hours on full load between major overhauls and high-speed light-duties automotive engines (service life only 2,000 to 5,000 hours). Although the cost for the automotive engines is five times lower than for industrial ones, they are suitable only for high-speed compressors, unless a gearbox is provided. Both types have relatively high efficiencies of around 35%.

2.1.2 Refrigeration equipment

As already mentioned in section 2, absorption chillers are the most commonly used equipment in trigeneration systems. For that reason and since the compression chillers are widely used in most standard appliances only absorption equipment will be described in this paragraph.

The main difference between absorption and compression chillers is that in the former the energy needed to transport heat from lower to higher temperature is heat energy, whereas in the latter it is mechanical energy. The absorption chillers use binary mixtures:

- A water/lithium bromide (Li Br) solution with high heat of vaporization (reduced heat- exchange surface area) and low vapour pressure (allows reduced shell thickness). It is non-volatile, non-toxic and non-flammable.
- An ammonia/water mixture having also high heat of vaporization but requiring a relatively high operating pressure (greater equipment shell thickness). The solvent is toxic, volatile and needs rectification.

The principle of absorption chillers can be explained using a water/lithium bromide machine example. The four basic sections of an absorption chiller are split into a high-pressure and low-pressure volume, although both operate under vacuum (Fig. 2). Hot water or steam generated in the WHRB flows through concentrator tubes and causes the dilute Li Br solution to boil. Water vapour (refrigerant) is released from the solution and passes to the condenser, where it is condensed by cooling water (e.g. from a cooling tower or a river). Condensed refrigerant is directed to the evaporator section through a pressure-reducing orifice. Here, the heat in the closed-circuit chilled-water return line vaporizes refrigerant, thereby cooling the flow of chilled water piped to the external load. Resulting water vapour passes to the absorber section and is absorbed into the concentrated aqueous Li Br solution. Plant cooling water circulates through the absorber tube to remove the heat of absorption. Concentrated Li Br, sprayed over the absorber tubes, absorbs steam and dilutes. The dilute solution is then pumped to the concentrator and completes the cycle.

In the double-effect absorption chillers the coefficient of performance (COP) is increased by using the water vapour generated in the first concentrator to generate the steam in the second, thereby reducing the heat required for condensation. The average COPs for single-and double-effect absorption chillers are 0.7 and 1.2, respectively [5].

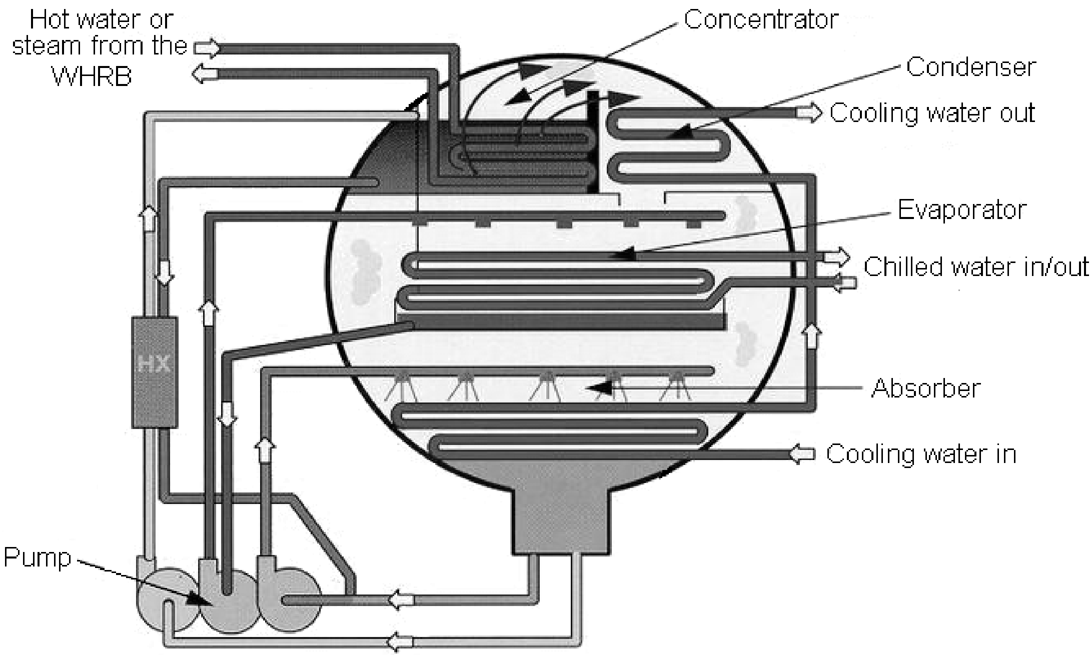

Figure 2 : Schematic of a typical Li Br absorption unit.

2.2 Economics

Analysis of a trigeneration system is a complex matter. There are several reasons for this.

- Electricity tariff rates as well as heat and refrigeration demands vary seasonally, and throughout the day. They also change over the years, which makes the calculation of pay-off time difficult.
- Peak demand for one output may not correspond to that for another. For example, in the summer, peak demand is usually for refrigeration, but not for heating (CERN's case). During winter, this situation may be completely reversed.
- A trigeneration system must satisfy peak demand for all outputs, while at the same time not remaining too idle during more characteristic heat-load combinations [6].

During a project's feasibility study, it is absolutely necessary to investigate different process schemes. The optimum scheme depends on relative tariff rates for electricity and gas, as well as relative demand for each output. Furthermore, trigeneration equipment is often available in standard packages. It is worthwhile to investigate the suitability of such readily available packages for the particular applications.

A techno-economic analysis must include the calculation of pay-back time. For this, both annuity (real annual investment cost including depreciation) and annual operating costs must be taken into consideration and compared to the annual benefits of the plant. The typical pay-back time for the trigeneration installation is some three to four years [4].

The shortest pay-back period occurs where there is a worthwhile year-round demand for heat. The ideal trigeneration heat loads come from continuous process industries, where steady heat and power supplies are needed throughout the year. If the process shuts down at night, at weekends or even for annual plant maintenance, the trigeneration benefits can diminish greatly.

2.3 Example of a trigeneration installation

One of the most obvious examples of trigeneration installations is the urban production and distribution of heating and cooling for the EXPO'98 exhibition zone in Lisbon [8]. This project was led by a global strategy of energy efficiency both concerning the rational use of energy and environment.

The whole system is basically composed of a thermal-power plant (trigeneration), heating and cooling distribution network and substations with heat exchanger units. The central thermal-power plant comprises.

- 1 SOLAR gas turbine type TAURUS 60 with nominal electric power of 5 MW and the WHRB (12 MW steam, with post-combustion);
- 2 CARRIER ammonia compression chillers with nominal cooling capacity of 6.0 MW each;
- 2 CARRIER ammonia absorption chillers with nominal cooling capacity of 5.0 MW each;
- 1 STEIN FASEL auxiliary steam boiler with 15 MW thermal capacity;
- 1 storage tank of 15,000 m^3 for chilled water.

The production of useful energy in 1998 was as follows:

Power production ....34 GWh
Heat production..25 GWh
Chilled-water production ....80 GWh

3 APPLICATION AT CERN

So why not apply such a winning scheme at CERN, where the three products are needed and where energy concerns have become so important in recent years? Let us limit our investigation to the Meyrin site where the cogeneration plant already exists. Besides this, the immense distance between different points on LEP or SPS also leads us to the choice of the Meyrin site as the most appropriate in terms of investment savings.

3.1 Description of the present energy scheme at CERN

The cogeneration plant was erected at the end of 1996 and consists of the gas turbine (4.8 MW) with the WHRB that complements Meyrin's heating system with some 7.6 MW of superheated water. The cogeneration plant has a total efficiency of about 78%, of which 30% is for electricity and 48% for useful heat generation [9].

The WHRB is incorporated into the main hot-water distribution network that serves the whole Meyrin site as well as point 1 of LEP and the SM18 complex. The hot water produced in the heating/cogeneration plants is delivered to the numerous substations located in different buildings and equipped with heat exchangers.

The production of refrigeration (chilled water) is being carried out in the individual users' chilled-water stations; therefore there is no common chilled-water distribution network at CERN.

However, the energy demands for the Meyrin site are very unstable compared to industrial applications and mainly depend on the experiments. One can distinguish the periods having more less constant demands for energy, see Table 1.

Table 1
Energy demands for the Meyrin site

	Electricity (%)	Heat* (%)	Chilled water (%)
Dec.– Feb.	40%	100%	20%
March – May	100%	40%	80%
June – Sept.	100%	0%	100%
Oct. – Nov.	100%	40%	80%

* not including demand for hot sanitary water

Being a very big consumer of electricity (some 157.6 GWh/year), CERN benefits from low electricity tariffs. In fact the price of electricity is so low, that CERN's primary fuel (natural gas) becomes even more expensive than the electricity in the summer months, as is shown in the following table.

Table 2
Energy demands for the Meyrin site

	Electricity (CHF/kWh)	Gas (CHF/kWh)
Dec., Jan., Feb.	0.087	0.034
Nov., March	0.0611	0.034
Oct., April	0.0505	0.034
May, June, Sept.	0.044	0.034
July, August	0.029	0.034

In addition to this, the foreseen developments in energy policy show a tendency for the price of electricity to fall, with also a slight reduction of gas prices.

3.1 Feasibility study

The price of 1 kWh produced by the cogeneration plant is some 0.06 CHF (maintenance costs excluded), which shows that in order to save money the turbine should be run only during the period from November to March (see Table 2). Furthermore, when compared with the prices of electricity and gas, one can immediately see that the use of absorption chillers is economically unjustified (the price of heat energy must be at least six times less expensive than electricity in order for the absorption concept to be profitable). In such a situation it is obvious that the operation costs of a trigeneration plant would exceed just the costs of purchasing these energies from the external suppliers. For this reason, further analysis of the investment cost is devoid of sense.

4 CONCLUSIONS

Trigeneration has a major role to play in answering the energy needs of commerce and industry. Its greater efficiency reduces emissions and fuel bills, and makes users more productive and competitive. However, although trigeneration offers a highly efficient way of converting primary fuel to useful energy its implementation must be preceded by very detailed feasibility studies involving economic analyses.

In our case these studies prove that implementation of trigeneration at CERN is not profitable because of the very low price that CERN pays for electricity. Given that the demand for heat energy during the summer season is negligible and that the use of absorption chillers is economically unjustified, compared to compression chillers, the main feature of the trigeneration concept – heat recovery– does not apply to our situation. Furthermore, also the existing energy distribution scheme does not allow the infrastructure to be adapted in a simple way to a district cooling system. Taking all these reasons into account, we can conclude that CERN’s policy for refrigeration production should focus on the use of very efficient compression chillers serving the individual users.

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